Extreme coastal water levels with tectonic motions along the South American Pacific coast

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INTRODUCTION

Extreme Coastal Water Levels (ECWL) along the South American Pacific Coast (SAPC) emerge from the combined influence of tides, sea-level anomalies, storm surge, and wave run-up, superimposed on long-term vertical land motions (VLM) driven by rapid plate convergence between the Nazca and South American plates. Secular uplift or subsidence rates are in the order of millimeters per year and episodic coseismic displacements of up to meters. These tectonic effects are comparable to or larger than projected sea-level rise (SLR) over multi-decadal scales, yet they remain largely underrepresented in global assessments of relative sea level and coastal flooding. This study combines observational and modeling approaches to characterize historical and future ECWL and evaluates their interaction with VLM for improved coastal hazard assessments.

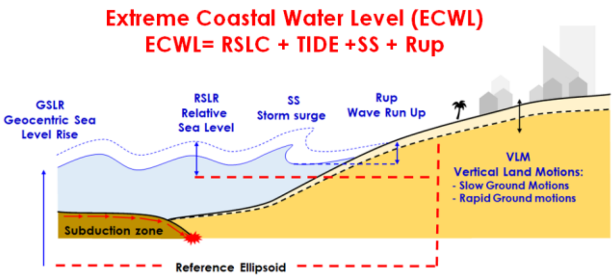

Figure 1: Vertical changes schematization in coastal areas

DATA

The historical period 1913-2019 combines measurements and numerical modeling data. OSU-TPXO model was used to obtain the AT, sea level anomalies (SLA), and absolute dynamic topography (ADT) from Copernicus satellite data and JRA-55 reanalysis was used to obtain SS and waves hindcast. Foreshore slope values obtained from the CoastSat website were used to obtain Rup2%. Seamless experiment, climate simulation from 1950 to 2099, was considered to obtain the future storm surge and ocean waves for ECWL estimations (Shimura et al., 2022). Storm surge was obtained from global simulations, forced by hourly sea surface winds, sea level pressure, monthly SIC, and wave projections for the wave run-up obtention in the same period

To represent VLM, three complementary datasets were used SAT–TG differencing (1993–2020) for long-term point-based deformation rates, InSAR Sentinel-1 (2020–2025) for high-resolution spatial deformation, and CMIP6 VLM (2005–2120) as a baseline. In addition to the previous data, we integrate Slab2.0 subduction geometry to define the megathrust fault plane for stochastic rupture modeling, and GEBCO global bathymetry to represent nearshore topography.

METHODOLOGY

ECWL along the SAPC were obtained following the expression in Figure 1. Average relative contribution (ARC) for the top 5% events to understand the changes in the ECWL between the historical and future conditions, was obtained as mean(AT) / mean(ECWL) + mean(SLA) / mean(ECWL) + mean(storm surge) / mean(ECWL) + mean(Run-up) /mean(ECWL) =1x100

Obtention of VLM along the SAPC in TG positions will allow us to obtain linear trends, that were extrapolated until 2100. Five cities were selected along the SAPC, Manta, Ecuador; Callao, Perú; Iquique, Valparaíso, and Talcahuano in Chile to conduct high resolution VLM by InSAR, where line-of-sight velocities (LOS) into vertical and horizontal components where combined. We obtain the spatial distribution from 2005 to 2020 and then from 2020 to 2120 from CMIP6. After obtaining different VLM spatial variability was compared. The differences between InSAR, SAT–TG, and CMIP6 were quantified to assess biases and uncertainties in their projections, integrating the VLM trends into CMIP6 SSP5-8.5 sea-level rise scenarios to produce corrected RSL through 2120. Lastly, we analyzed stochastic earthquake scenarios generated by discretizing the slab geometry into subfaults and assigning heterogeneous slip distributions following spectral scaling laws (Goda et al., 2016).

RESULTS

ECWL 27-year hindcast obtained along the SAPC shows median values of 1.0 to 1.5. m with maximum median values of 2.5 m. When the superior 5% is analyzed, Rup2% is the main contributor among the variables for reanalysis (60% to 70%) and projections (median value of 38%). Projections analyzed show that SLR and median values of the relative contribution will vary between 25% and 35%. Storm surge contribution along SAPC in historical and projections analyzed are minor, at 5% to 10%.

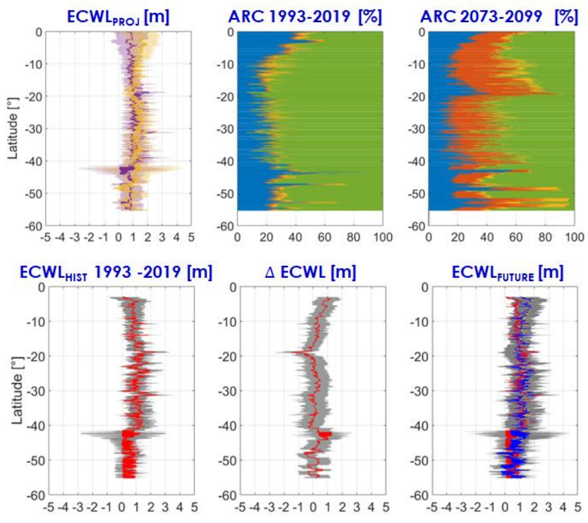

Figure 2:Extreme coastal Water levels ARC

Correcting SLR projections with the obtained VLM produced notable differences by 2100 under the SSP5-8.5 scenario (Figure 3). SAT–TG corrections increased relative SLR projections by +0.22 m in Manta due to subsidence, while reducing projections by –0.64 m in Talcahuano, where uplift dominates. On the other hand, Coseismic deformation for an earthquake Mw 8.3 (Figure 3) can generate subsidence/uplift of-0.5 m to 1.37 m, overpassing SLR ratios in a question of seconds.

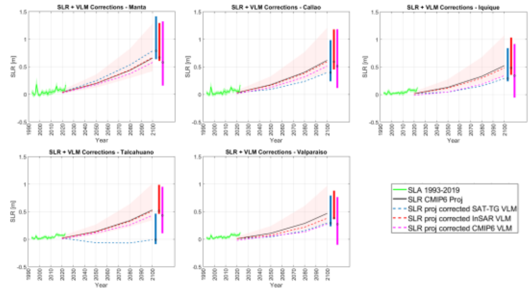

Figure 3: Sea level rise projections

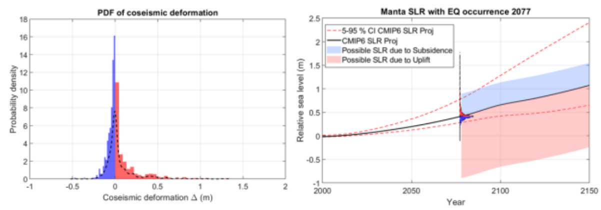

Figure 4: Coseisimic deformation and its influence in sea level rise projection for an 8.3 Mw earthquake.

CONCLUSION

Regional Relative Sea level is complex in both time and space, driven by climatological and geophysical phenomena's. Leading to a necessary understanding of each component for adaptation and disaster risk mitigations Neglecting key components can remove half of the total signal, and VLM alone can match the scale of projected sea-level rise. Furthermore, earthquake-related uncertainties of similar magnitude have the potential to reshape future scenarios

REFERENCES

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Shimura, T., Pringle, W. J., Mori, N., Miyashita, T., & Yoshida, K. (2022). Seamless Projections of Global Storm Surge and Ocean Waves Under a Warming Climate. Geophysical Research Letters, 49(6). https://doi.org/10.1029/2021GL097427